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INVESTIGATION OF TEST METHODS
MATERIAL PROPERTIES, AND PROCESSES
FOR SOLAR CELL ENCAPSULANTS

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ENCAPSULATION TASK OF THE LOW-COST
SILICON SOLAR ARRAY PROJECT

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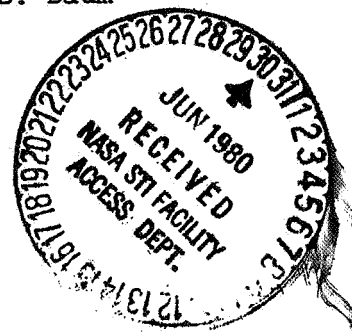
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I. SUMMARY

Springborn Laboratories is engaged in a study of evaluating potentially useful encapsulating materials for Task 3 of the Low-Cost Silicon Solar Array project (LSA) funded by DOE. The goal of this program is to identify, evaluate, and recommend encapsulant materials and processes for the production of cost-effective, long-life solar cell modules.

Work performed during this quarter included the development of anti-blocking treatments for EVA sheet intended for use as a lamination pottant. The polymer has a high surface tack which presents handling problems in manufacturing operations. The most effective treatment was found to be coextrusion with non-woven glass cloth to provide a non-stick surface. The glass cloth is also useful in aiding vacuum degassing during lamination and additionally provides a mechanical barrier between module components. Alternatively, the EVA sheet may be dusted with a fine powdered grade of polyethylene to yield an effective non-sticking surface.

Initial evaluation studies were begun on a new pottant compound, polybutyl acrylate, to assess its preparation and handling characteristics. This is a transparent casting syrup that thermosets at elevated temperature (80°C) and may be stored as a one part system. This compound shows promise as a cost effective encapsulant, but more development is required to speed the cure cycle and improve the processing characteristics.

Corrosion studies using a standard salt spray test were conducted to determine the degree of protection afforded to a number of metals when encapsulated in candidate pottant compounds. Excellent protection (1600 hours of exposure) was provided to copper, galvanized steel, mild steel and aluminum when primed with silanes and encapsulated in EVA. The metals showed no signs of corrosive attack under these conditions. Unprimed specimens and encapsulation by pottants other than EVA did not perform as well. The corrosion sensitivity also appears to be dependent on the combined chemistry of the materials.

Pottants and outer cover candidates were exposed to intervals of accelerated UV stress aging using the RS/4 fluorescent sunlamp. A summary of the past two years work was tabulated and the results noted. Two outer cover materials were

examined, Korad acrylic film and Tedlar fluorocarbon. The Korad demonstrates much lower resistance to UV than expected, the specimens degrading with embrittlement after as little as 1000 hours exposure. Tedlar film survived very well with no measurable signs of degradation. The candidate pollutants varied in performance. Polyurethane, even when protected with cover films, degraded fairly rapidly. EPDM survived up to 6000 hours when properly stabilized and covered with a protective film, but still showed signs of slow degradation in the best case. Compounded and stabilized EVA has excellent performance, showing no signs of degradation after 9,000 hours of exposure even without the benefit of a protective film.

II. INTRODUCTION

The goal of this program is to identify and evaluate encapsulation materials and processes for the protection of silicon solar cells for service in a terrestrial environment.

Encapsulation systems are being investigated consistent with the DOE objectives of achieving a photovoltaic flat-plate module or concentrator array at a manufactured cost of \$0.70 per peak watt ($\$7/\text{ft}^2$) (1980 dollars). The project is aimed at establishing the industrial capability to produce solar modules within the required cost goals by the year 1986.

To insure high reliability and long-term performance, the functional components of the solar cell module must be adequately protected from the environment by some encapsulation technique. The potentially harmful elements to module functioning include moisture, ultraviolet radiation, heat build-up, thermal excursions, dust, hail, and atmospheric pollutants. Additionally, the encapsulation system must provide mechanical support for the cells and corrosion protection for the electrical components.

Module design must be based on the use of appropriate construction materials and design parameters necessary to meet the field operating requirements, and to maximize cost/performance.

Assuming a module efficiency of ten percent, which is equivalent to a power output of 100 watts per m^2 in midday sunlight, the capital cost of the modules may be calculated at \$70.00 per m^2 . Out of this cost goal only 5.4 percent is available for encapsulation due to the high cost of the cells. The encapsulation cost allocation may then be stated as \$3.80 per m^2 (\$0.35 per ft^2) which includes all coatings, pollutants and mechanical supports for the solar cells.

Assuming the flat plate collector to be the most efficient design, photovoltaic modules are presently envisioned as being composed of six basic construction elements. These elements are (a) outer covers; (b) structural and transparent superstrate materials; (c) pollutants; (d) substrates; (e) back covers; and (f) adhesives. Current investigations are concerned with identifying and utilizing materials or combinations of materials for use as each of these elements.

Extensive surveys have been conducted into many classes of materials in order to identify a compound or class of compounds optimum for use as each construction element.

The results of these surveys have also been useful in generating first-cut cost allocations for each construction element, which are estimated to be as follows (1980 dollars):

<u>Construction Elements</u>	<u>Cost Allocation (\$/Ft²)</u>
Substrate/Superstrate	0.19
Pottant	0.08
Adhesive	0.06
Outer cover	0.01
Back cover	0.07

From the preceding work, it became possible to identify a small number of materials which had the highest potential as candidate low cost encapsulation materials. The following chart shows the materials of current interest and their anticipated functions:

<u>Candidate Encapsulation Materials</u>			
<u>Structural Element</u>	<u>Elastomeric Pottant</u>	<u>Cover</u>	<u>Adhesive</u>
<u>Superstrate Design</u>	Ethylene/vinyl acetate Ethylene/propylene diene Polyvinyl chloride	Mylar Tedlar	As required
Soda-Lime Glass	plastisol Poly-n-Butyl acrylate Aliphatic Polyurethanes	Aluminum foil Silicone/Acrylic polymers	
<u>Substrate Design</u>			
Fiberboard		Korad 201-R	
Flakeboard	(same as above)	Tedlar 100 BG	
Mild steel		30 UT	
Glass reinforced concrete			

This report presents the results of the past quarter which has been directed at the continuing development and testing of pottants, outer covers, encapsulation processes and other components and techniques which may be useful for the fabrication of cost effective solar modules. The topics covered in this report are as follows:

- (1) The assessment of techniques for imparting a non-sticking or anti-blocking property to EVA sheet. The aggressive adhesion encountered with EVA surfaces poses a difficulty to certain module manufacturers and interferes with the free winding of the material in roll form. Three approaches to this problem are discussed; embossing the surface, dusting with a powdered material and coextrusion with non-woven glass mat.
- (2) A new pottant, polybutyl acrylate, was prepared and an initial investigation of its module processing and curing characteristics was examined.
- (3) Corrosion studies. A variety of metals were encapsulated, both primed and unprimed, in each of the candidate pottants under current investigation. The specimens were exposed to a harsh salt spray condition at 35°C and the degree of attack compared.
- (4) The results of the last two years work with the exposure of candidate pottants and outer cover materials to RS/4 fluorescent sunlamp have been tabulated and compared. This method provided data concerning the relative resistance of accelerated UV stress to the degradation of mechanical properties in materials exposed to specified time intervals.

III. ANTI-BLOCKING EXPERIMENTS

One of the problems presented by EVA polymer pottant in sheet form is that of its aggressive surface tack. Two sheets of pottant coming in contact with each other are separated with difficulty, if at all. Additionally, other materials coming in contact with the sheet, such as cells, interconnects, etc. may similarly adhere and prevent movement of components placed on the sheet. This difficulty has been encountered by some commercial module manufacturers using EVA in trial fabrications. From a production standpoint, the sticking or "blocking" property of the film is a disadvantage because it necessitates the use of a disposable release paper interleaving. This increases the production cost, is an inconvenience at film winding stations, and increases the shipping weight.

A number of approaches have been investigated recently for a possible solution to this problem. The first approach was dusting the surface with a compatible type of powdered material to physically separate the plies, the second was embossing the surface to give a non-adhesive matte finish, and the third was separation with non-woven glass cloth.

Different types of dust were evaluated for the surface dusting approach. Included were several grades of fumed silica, two types of Kynar dispersion, finely ground PVC resin and a polyethylene powder. All the dusting materials were found to be effective anti-block agents, permitting the EVA polymer to be rolled up in sheet form without adhesion between the plies. Difficulties were encountered, however, when these EVA surface treatments were used in module fabrication experiments. Experimental two celled modules were found to have large areas of opacity where the dust particles had agglomerated and a general haze over the cells due to the incompatibility of the powdered material. This effect was noticed with all the dusting compounds used with the exception of the polyethylene powder. No disturbance of the optical path was detectable with the polyethylene powder, either visually or by I/V curve measurement. This success is thought to be due to the closely matched refractive indices of the two polymers (EVA has $n_d = 1.48$; low density polyethylene has $n_d = 1.5$) and also to the mixing during the melt phase. The EVA base resin has a melt index of 40, the polyethylene is approximately 70. This indicates that both resins have very low melt viscosities and probably mix with little difficulty during the lamination

process. The grade of polyethylene selected for this experiment is available from U. S. Industrial Chemicals Inc. and is tradenamed "Microthene" - MN-714. This material is a low density polyethylene that softens at 83°C (Vicat), has a particle size of 50 U. S. mesh and is sold for \$0.46/lb in bulk. In treatment, the surface of the EVA sheet is allowed to pick up the amount of dust that will naturally adhere to it (approximately 0.4 gm/ft²). This can be done by brushing the dust on the surface and blowing the excess off with an air jet. In production, the extruded sheet would probably be passed through a fluidized bed of dust in line with the extruder and then wound directly onto cores. A commercial production process such as this has not been implemented yet for use with EVA.

The next anti-blocking treatment investigated was that of embossing the surface to give a matte finish. Laboratory samples were prepared by compression molding EVA (below cure temperatures) between sheets of aluminum that had been abraded so that the surface texture would be transferred during molding. The aluminum plates were abraded by sandblasting. A 220 mesh grit was used at a pressure of 100 psi to roughen the surface with a uniform spray pattern. Due to difficulty with the removal of the molded resin from the plate, the embossing surface was changed to Teflon FEP. The 20 mil FEP sheet was abraded in the same manner as the aluminum plate and was as effective in transferring the surface texture to the resin which could then be removed without difficulty. The embossing technique also appears to be quite successful in preventing the sheets from adhering. No adhesion between the plies can be noticed, even when considerable pressure is applied by winding in roll form on a core. Embossing the surface of one or both sides could also be incorporated as part of the extrusion process by passing the hot resin through a pair of rollers covered with abraded FEP sleeves. The sheet could then proceed to the roll stand and be wound without the use of the release paper interleaving. The benefit of this approach is also that the expense lies only in a capital equipment cost for the rollers and no other supply of raw materials is required.

Another anti-blocking modification that has shown success has been the extrusion of the resin directly onto a sheet of "Craneglass" non-woven glass cloth. This results in a predictably effective anti-blocking surface by providing mechanical separation of the two surfaces. Small laboratory extrusion samples were prepared using this technique with "Craneglass" type 230 of 5 mils thickness.

The method worked well; however, a small amount of pressure is required to cause the resin to adhere well to the glass fiber. In production, the extruded resin and glass cloth must be run simultaneously through a nip roller to insure good contact. Preparing the pottant in this manner presents the advantage of eliminating the release paper interleaving and also having the glass cloth already in place. The "Craneglass" improves the module evacuation/lamination process, provides a layer of mechanical separation between components and improves the insulation resistance of the composite. The use of this type of anti-blocking treatment implies that a layer of the glass cloth will be present over the cells in fabricated modules. Experiments were conducted to determine the optical effect of this material when placed in the light path over the cell. A specimen of EVA/Craneglass was prepared by compression molding and submitted to spectroscopy. Despite the increase in visible haze, the light throughput remained high. Total integrated hemispherical transmission was found to be in the order of 93%, consequently no loss in module power is expected from the inclusion of this material in the lamination. A module prepared using this technique was evaluated by I/V curve determination and compared to another module without the included glass cloth. No difference in performance could be detected.

Although all three methods discussed here gave very good results, a further evaluation was required in order to determine the effectiveness of these approaches under simulated storage conditions. ASTM describes three tests for the determination of anti-blocking efficiency:

1. Blocking of Plastic Film; D-1893-67
2. Blocking Load of Plastic Film by the Parallel Plate Method;
D-13354-74
3. Blocking of Potentially Adhesive Layers; D-1146-43

The best method is probably the first which uses large areas of film and can measure the degree of blocking quantitatively. This method also has provision for changing the load and temperature of the test specimens. This test was applied to the three techniques, using 4 plies of each under a load of approximately 0.15 psi and a temperature of 120°F. These conditions were selected to simulate storage conditions in a roll in a hot warehouse. After 350 hours, the specimens were removed and evaluated by attempting to separate the plies.

The specimens employing the embossing technique were totally blocked and the plies could not be separated at all. The specimen dusted with polyethylene powder separated easily with a little force due to some areas that had been insufficiently coated with powder and had "wetted through". The specimens bonded to glass cloth separated easily with a minor amount of adhesion between the plies. The results of the tests indicate that the glass cloth extrusion technique is probably the best, although not much better than the surface dusting conditions. The dusting technique can possibly be improved by a more appropriate choice of particle size, melt flow or application technique with polyethylene dispersion. Two new grades of successively smaller particle size (Microthene FN-524 and FN-510; US Industrial Chemicals) are currently under evaluation.

IV. BUTYL ACRYLATE POTTANT

Investigations of pottants other than EVA are currently underway. Compounds such as EPDM rubber and aliphatic urethane products are under test for weatherability, transparency, thermal cycle testing, etc.

These compounds represent "second choice" materials in the event that the EVA pottant appears to be unsuitable for a particular module design or process. This, hopefully, will also result in a few alternate choices of pottant for solar module manufacturers who may be pursuing different fabrication concepts than those emphasized in this report.

The criteria for the selection of alternate pottants are essentially the same for EVA; high transparency, processability, weatherability (or the potential to be made weatherable) and attractive cost.

A compound identified by JPL, poly-n-butyl acrylate, appears promising as a casting syrup due to its transparency, weatherability low modulus and low cost. Work has just begun on this compound to assess its usefulness as a candidate liquid-potting compound. The syrup itself is a transparent fluid composed of premade polymer (solid) dissolved in monomer (liquid) and a small quantity of a catalyst to initiate the cure reaction.

The first step in the formulation of this syrup is the preparation of the prepolymer. This is done by a simple solution polymerization in which the equal weights of butyl acrylate monomer and cyclohexane solvent are mixed and then catalyzed with 0.01 weight percent of AIBN (azobisisobutyronitrile). The mixture is stirred under nitrogen to remove the air and then heated to 80°C for a period of 15 hours. The polymerization occurs during this time and a solution of polybutyl acrylate in cyclohexane solvent remains. This solvent is stripped off under vacuum for storage and recycling in the next reaction. The yield of polymer is quantitative and it remains in the flask as a crystal clear tacky resin of an estimated molecular weight of 400,000 (\overline{M}_w -GPC). More liquid monomer is then added to the flask to dissolve the polymer and yield a 100% active acrylic based casting syrup. For the initial experiments, a 33% w/w polymer/monomer solution was prepared. This syrup is completed by the addition of 0.01% AIBN catalyst to serve as the initiator during the cure reaction. The syrup so prepared is a transparent fluid of 10,000 centipoise viscosity which may be used directly as the solar module pottant. The anticipated commercial process for the manufacture of this compound is shown in Figure 1.

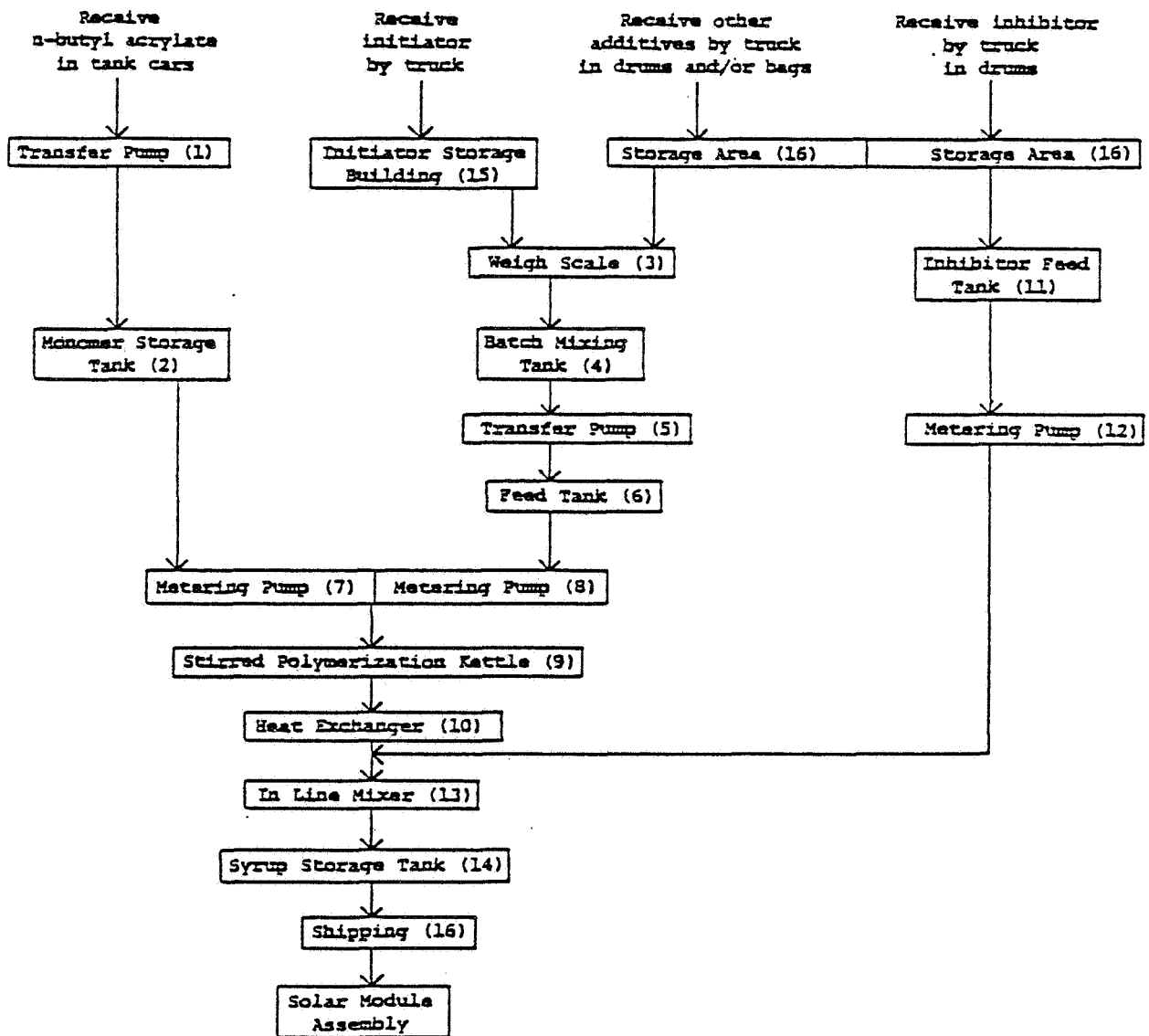
The precatalyzed syrup appears to be quite temperature stable (at room temperature) and shows no problems of long-term storage when kept under normal conditions. The activation temperature is in the order of 50°C. This is the temperature at which the initiator will become active and polymerization begins. The visible onset of gel (sharp increase in viscosity) is approximately 1 hour at 60°C. Although polymerization will occur at these temperatures, the cross-linking reaction that causes the syrup to become thermoset does not become active until 80°C is reached. The module manufacturing process should be capable of achieving this temperature in order to prepare fully cured modules capable of passing the JPL thermal cycle test.

Initial attempts to prepare experimental modules with this compound were not immediately successful due to lack of technique in terms of handling this material. A jig is required that serves to hold the front and back covers in place so that the fluid may be pumped in without leakage and loss. The jig must also be capable of holding the assembly throughout the heating and curing cycle. First attempts failed due to loss of pottant due to poor edge sealing. Masonite/Tedlar modules bonded with adhesives leaked due to attack on the adhesive. Other designs incorporated silicone rubber gaskets sandwiched and clamped between two rigid supports; the Masonite on one side and the Tedlar film supported by a sheet of aluminum on the other. Two holes were left in the gasketing to permit the filling and overflow of pottant. The clamped assembly, after filling, was then transferred to an air oven set for 80°C. The cure process is complete after 3-5 hours and the modules were removed and permitted to cool. The pottant was found to have cured to a crystal clear tough rubbery compound and was almost completely bubble free. The Tedlar film was somewhat wrinkled on the back due to shrinkage of the resin during the cure process. A larger 11 celled minimodule is currently under construction for JPL temperature cycling and will use refinements in technique and possibly formula.

The initial impression of butyl acrylate syrup is encouraging, however, changes in the formulation may tend to improve the processing characteristics. Using higher resin solids, perhaps up to 50%, will reduce the shrinkage of the resin during the cure stage and prevent the warping of the flexible outer cover films. Faster cure at lower temperatures may also be possible by the more appropriate selection of the initiator compound. Many aliphatic peroxides and azo compounds are available that could speed the process considerably. An increase in the initiator level to 0.1% may also be beneficial.

FIGURE 1

PRODUCTION FLOW CHART
BUTYL ACRYLATE SYRUP



V. CORROSION STUDIES

Experiments were conducted to determine the relative amount of corrosion protection that could be provided to metallic components of a solar module by encapsulation in the candidate pottants. This experiment employed an ASTM procedure, number B-117, in which the specimens are exposed to a continual spray of salt fog containing 5 parts by weight of sodium chloride and at a temperature of 35°C. This test is generally regarded as severe in the paint and coating industries and results in rapid corrosion of inadequately protected metals.

The metals included in this test were aluminum, galvanized steel, mild steel and copper. The tests were run on both unprimed and primed metals which were encapsulated in EVA, EPDM, PU (polyurethane) and PVC plastisol. Specimens were prepared by compression molding the metal squares between two sheets of resin and subsequently curing in the case of EVA and EPDM pottants. With the thermoset liquid pottants, PU and PVC plastisol, the metal specimens were placed in shallow molds and the liquid cast around them. Additionally, whole experimental modules containing two cells and prepared by a candidate manufacturing method were also placed in the chamber to determine the effects on whole encapsulation systems. The test specimens were examined and subjectively rated for the degree of corrosion at intervals of 24, 120, 300, 450, 700 and 1600 hours of exposure. The test results are presented in Tables 1 through 4. The corrosion testing with EVA was covered in a previous report^(a), but a table of the results has been included for the purpose of comparison.

Prior to the onset of these tests unencapsulated metal control specimens were exposed to determine the baseline corrosion rate. These specimens exhibited corrosive attack within the first few days. The most sensitive metals were found to be copper and both the mild and galvanized steels. These materials showed distinct signs of attack after six hours exposure. Aluminum was a little more resistant, showing the same degree of attack after about fifty hours. All the unencapsulated metals were rated as corroded or severely corroded after 120 hours exposure.

(a) Springborn Laboratories, "Investigation of Test Methods, Material Properties and Processes for Solar Cell Encapsulants" Third Annual Report, JPL Contract 954529, June 1979

The results of unprimed encapsulated metals is presented in Table 1, and it can be noticed that the degree of protection provided by the pottant varies according to the metal/pottant combination. In general, the aliphatic poly-ether urethane (PU) gave less protection than either the plastisol or EPDM. All the metals corroded faster in the urethane than the other two, with copper developing noticeable blue-green corrosion products within 120 hours. The plastisol provided slightly better protection and the EPDM formulation was, perhaps, marginally better yet. In terms of specific metals some more definite conclusions can be made. Galvanized steel was well protected by both EPDM and the plastisol, showing no discernable signs of corrosion after the full 1600 hour exposure period. Mild steel was not protected well by any of the formulations and copper corroded in all cases except in the plastisol, where only a slight dull coating could be noticed. Aluminum appeared to be the least corrosion sensitive metal and showed no signs of corrosion in EPDM or the urethane and showed no signs of attack in the plastisol until the 1000 hour mark. This series of experiments was repeated with the use of silane primer^(a) applied to the metal specimens prior to encapsulation. Primers were expected to improve the corrosion resistance by providing a strong bond at the polymer/metal interface. This appears to be generally supported by the experiments conducted to date. The primed metals performed either equivalently or significantly better than the unprimed specimens with the single exception of galvanized steel in EPDM. The corrosion sensitivity reversed in this experiment with the metal showing no signs of corrosion in the unprimed form and severe corrosion when primed. As with the unprimed control metals, galvanized steel is best protected by EPDM and the PVC plastisol, copper is best protected by the plastisol but not by the urethanes or EPDM, and mild steel is not well protected by any of the candidates. Aluminum appears to be the most resistant to corrosion in all cases.

Table 4 compares the corrosion characteristics of all pottant/metal combinations attempted so far including the results of the EVA experiments performed in a previous reporting period. As may be seen in the table, the best results have been found for EVA and primed metals. After the 1600 hour salt spray exposure, no corrosion can be found in any of the primed metals encapsulated in cured EVA. The next best performance is generally found for the PVC plastisol

(a) A. Plueddemann, "Chemical Bonding Technology for Terrestrial Solar Cell Modules", JPL Document 5101-132, September 1979.

which gave good protection to aluminum and galvanized steel and only barely noticeable corrosion of copper.

Experimental two-celled modules were prepared and exposed to the same salt spray corrosion conditions as the encapsulated metal specimens. Four basic module types were used and consisted of (a) Glass/EVA/Aluminum foil-superstrate type, (b) EVA/Masonite/Korad-substrate type, (c) EVA/Masonite/Tedlar 100BG30UT-substrate type, and (d) EVA/Galvanized Steel/Korad-substrate type. These modules were mounted against a plywood board and supported along the edges with plastic pins. In all the modules, the first signs of corrosion were found on the exposed interconnects (solder plated copper) which formed a dull grey layer of corrosion products that appeared to give protection against further attack. Signs of other areas of corrosion appeared after 120 hours. In the substrate type modules employing Korad cover films corrosion of the interconnects beneath the film could be noticed as the formation of a grey film. This effect was not observed in the module using a Tedlar 100BG30UT outer cover film. Warping of the Masonite substrate modules was noticed and was most likely due to water absorption through the few areas where the covering of EVA over the hard-board was particularly thin. Similarly, in the galvanized steel substrate modules corrosion products could be noticed along the edges where the EVA was particularly thin. Upon inspection of these modules, the edges of the galvanized steel were found to have cut through the resin leaving them open for attack. The glass superstrate design module was perhaps the least effected losing about 10% of its back surface coverage of aluminum foil after the full 1600 hour exposure period. In all, the modules survived quite well and most of the degradation effects were observed within the initial 120 hour exposure period. No signs of discoloration or delamination were noticed.

It is felt that the optimum resistance to corrosion will result from matched systems of pottant/primer and metal component that have been individually tested for compatibility and maximum protection. Some insurance that complete coverage and total encapsulation by the pottant is required. The best corrosion resistance observed to date is found for primed metals in EVA.

VI. RS/4 FLUORESCENT SUNLAMP EXPOSURES

The degradation of polymeric materials in outdoor weathering is caused primarily by sunlight, especially the ultraviolet component. In actuality, the deteriorative effect of light is usually enhanced by the presence of oxygen, moisture, heat, abrasion, etc. and in many cases the deterioration is properly photooxidation.

Sunlight reaching the earth is filtered through the atmosphere, removing shorter wavelengths up to 290 mu before it reaches the surface of the earth. Thus ultraviolet effects on plastics result primarily from wavelengths of approximately 290-400 mu, which is approximately 5 percent of the total solar radiation reaching the earth.

The lower the wavelength of light, the more damaging is its potential to produce a chemical change in material. This energy must first be absorbed, however. Plastics differ considerably in their ultraviolet absorbing properties, but few are completely transparent in the 300 to 400 mu range. Once the radiant energy has been absorbed, the likelihood of chemical change will depend on the stability of the chemical bonds in the polymer. The induced chemical modifications are responsible for the deterioration of optical and mechanical properties and usually result in reductions of tensile strength, elongation and transparency.

These degradative effects may be simulated in the laboratory and accelerated to yield predictions about long-term behavior from short-term tests. A number of devices are commercially available for this type of testing and include equipment such as "Weatherometer", "Fadeometer", QUV, etc. One of the more popular and simple devices is the RS/4 exposure chamber. This device is a modification of standard test procedure ASTM D-1501, "Exposure of Plastics to Fluorescent Sunlamp", and is widely used throughout the plastics and other industries for the purpose of accelerated weathering. In this device test specimens are mounted on a turntable that rotates beneath a fluorescent sunlamp (General Electric RS/4 Type) in a closed chamber thermostatted to a temperature of 50°C. The specimens are removed for testing at appropriate intervals based on the degradation rate of the material under examination. For the purpose of determining the relative stability of pottant and outer cover formulations, a schedule of 60, 120 and 240 days exposure was used. This is equivalent to 1440, 2880 and 5760 hours.

As a point of comparison, unstabilized polypropylene is physically degraded after approximately 160 hours and unstabilized low density polyethylene is degraded after approximately 450 hours of exposure. The materials under test are, then, considerably more stable than either of these two polymers.

During the past two years, three series of specimens have been placed under RS/4 accelerated exposure, and evaluated for mechanical or optical properties or both after completion of the exposure intervals indicated. The attached Tables 5 through 7 summarize the results of these long-term tests and are presented as Series I, II and III exposures.

Series I exposures began in October of 1978 for the purpose of determining the stability of different EVA formulations and proving the feasibility of protecting polymers with UV absorbing films.

Three specimens of polypropylene were coated with a film of acrylic polymer containing a UV absorber at three levels; 2.5%, 5% and 10%. These acrylic solutions were prepared by National Starch and Chemical Corp. and contained Permasorb-MA absorber incorporated by polymerization. The specimen containing the least amount of absorber has only recently been removed from exposure due to film cracking and specimen degradation. The specimen removed had developed the characteristic white haze of degradation and additionally the outer cover had fractured. Testing the acrylic film by spectroscopy showed that the UV absorbing property was still effective. The specimen survived 11,500 hours of exposure, equal to 16 months. This corresponds to an improvement in the lifetime of polypropylene by a factor of approximately 100. The other two specimens are still under exposure and will be removed when signs of degradation appear. Although the formulation and vehicle for the UV absorbing film was not optimized or developed for use in solar modules, it serves to demonstrate that enormous improvements in polymer lifetime may be achieved with this approach.

Specimens of an early EVA formulation - A8326 - (with Sartomer-350, Lupersol 101 peroxide and stabilized with Cyasorb UV-531, Tinuvin 770 and Irganox 1076) were also removed for optical and mechanical testing. These specimens have remarkably endured over 10,000 hours of RS/4 exposure with no apparent change in properties. Although some haze has developed in the transparent specimens, the total integrated optical transmission is still 90.6% and the mechanical properties are identical to control. Three specimens in this series will be left

under exposure: White EVA (A8901D), a piece of EVA protected with the National Starch UV/acrylic film, and an unprotected piece of compounded and cured EVA (experiment No. A8901C). These EVA materials remaining under exposure will be removed on a periodic basis for inspection.

Series II specimens (Table 6) consisted of outer cover candidate materials, different formulas of EVA and EPDM and combinations of these pottants with the outer cover materials. Some compounds degraded before the 60-day exposure was complete. EPDM and EVA formulations cured with peroxides (but not stabilized) discolored and softened into sticky masses before the mechanical tests could be performed. All these specimens were removed before the tests were continued. At the 60-day point, all the other test specimens showed no signs of degradation or variation in properties with one exception; Korad 201-R. Specimens of Korad were too brittle to be clamped in the test machine and broke upon handling. The 120-day exposure properties also showed no degradation of the test materials with the exception of the Korad 201-R. The samples of properly compounded and stabilized EVA and Tedlar showed no signs of change. Unfortunately the 240 day exposure samples were destroyed by an accidental thermal over-ride in the equipment. The chamber temperature is estimated to have exceeded 100°C and none of the specimens survived except the white EVA. All others were black to brown in appearance. Most of these specimens were repeated in the next series.

Series III (Table 7) RS/4 exposures consisted of further testing of EVA compounds and the inclusion of the aliphatic polyurethane and EPDM pottants. This time the 60-day evaluations were not performed, most of the materials of interest showing no signs of change at that interval. The unprotected urethanes were an exception, however, and were removed at the 60-day point. These materials in their unmodified form are very sensitive to UV degradation and flowed into diffuse shapes of dark yellow/brown color. The protected urethanes survived the remaining test periods, however, deterioration of the physical properties indicates that the degradation process is still in operation. Glass provided the best stability to the urethane at the 240 day exposure period, the tensile specimens retaining 960 psi of tensile strength and 440% elongation. The specimens behind Korad film lost about 90% of the original tensile strength and the urethane behind Tedlar film discolored and flowed completely to destruction. The compounded EPDM (A8945A) was sufficiently stable to survive the total 240

day exposure period but loss of tensile strength and elongation could be noticed in all the specimens including those placed behind a protective film of Korad, Tedlar and glass. Tensile strengths decreased in the range of 30% to 70%. EPDM is much more stable to UV degradation when compounded with stabilizing additives, however, it is still very much less stable than the EVA formulations of current interest. All of the EVA formulations, both pigmented and transparent, performed very well and although the test results had a rather wide range of values no significant signs of degradation were evident. Protection provided by glass and the screening films did not appear to influence the material properties significantly.

In conclusion, the polyurethanes appear to be the most difficult to protect from UV degradation, the EPDM formulations are more promising, but require work and the EVA copolymer appears to have very high stability.

VII. FUTURE WORK

Future work for the next quarter will include the following items:

1. Evaluation of two new types of polyethylene dust for the anti-blocking treatment of EVA sheet pottant in order to optimize the efficiency.
2. Determination of interference with adhesive bonding of EVA that has been treated with polyethylene powders.
3. Improvement of the cure properties of the butyl acrylate syrup pottant by increasing the solids content and selection of an optimized initiator.
4. Corrosion testing experiments will continue with copper, mild steel, galvanized steel and aluminum encapsulated in polybutyl acrylate pottant.
5. Candidate pottant formulations will be included in a new accelerated weathering condition; RS/4 sunlamp with water spray to determine the stability of the formulations when the potential for water extraction of stabilizer components is present.
6. The Q-623/Q626 polyurethane formulation will be screened in the RS/4 chamber with different UV stabilizers and additives to determine if the lifetime can be improved.
7. A study on gaskets and edge sealers for solar modules will be started.

TABLES

Table 1

CORROSION MONITORING
NEW POT TANTS - UNPRIMED CONTROLS

Test Specimens		Corrosion Conditions							
		Salt Spray ASTM B-117-73							
Notebook No.	Materials	Primer	24 Hrs	120 Hrs	300 Hrs	450 Hrs	700 Hrs	1600 Hrs	
A10966-1	Copper /EPDM (8945A)	None	1	1	1	2	4	4	
-2	Aluminum/EPDM - same	None	1	1	1	1	1	1	
-3	Mild Steel/EPDM - same	None	1	2	4	4	3	4	
-4	Galvanized/EPDM - same	None	1	1	1	1	1	1	
-5	Copper/PU	None	1	3	4	5	5	6	
-6	Aluminum/PU	None	1	1	1	1	1	1	
-7	Galvanized/PU	None	1	2	3	4	4	6	
-8	Mild Steel/PU	None	1	2	3	4	4	6	
-9	Copper/Plastisol A10585-1	None	1	1	1	1	2	2	
-10	Aluminum/Plastisol - same	None	1	1	1	1	1	4	
-11	Galvanized/Plastisol - same	None	1	1	1	1	1	1	
-12	Mild Steel/Plastisol - same	None	1	2	4	4	4	6	

Legend:

- | | | |
|----------------------------------|--|------------------------------|
| 1. Unaffected | 5. Medium corrosion visible (10% of surface) | 7. Discoloration of polymer |
| 2. Slight dulling of surface | 6. Heavy corrosion visible (over 20% of surface) | 8. Delamination at interface |
| 3. Noticeable dulling of surface | | |
| 4. Light corrosion visible | | |

Table 2

JPL 6072.1.1.5

CORROSION MONITORING

Primed Specimens

Test Specimens			Corrosion Conditions					
Notebook No.	Materials	Primer	Salt Spray ASTM B-117 (Hours)					
A10980 - A1	EPDM/Galvanized Steel	Z6029/6030 ^(a)	24	120	300	450	700	1600
- A2	EPDM/Copper	same	1	3	4	5	6	6
- A3	EPDM/Aluminum		1	1	1	1	2	2
- A4	EPDM/Mild Steel		1	1	1	1	1	1
A10981 - B1	PU/Galvanized Steel		1	2	2	2	2	2
- B2	PU/Copper		1	1	1	1	1	3
- B3	PU/Aluminum		1	1	1	2	1	2
- B4	PU/Mild Steel		1	1	1	1	1	2
A10981 - C1	PVC Plastisol/Galvanized		1	3	5	5	5	6
- C2	PVC Plastisol/Copper		1	1	1	1	1	1
- C3	PVC Plastisol/Aluminum		1	2	2	2	2	2
- C4	PVC Plastisol/Mild Steel		1	1	1	1	1	1
			1	2	4	5	5	5

(a) Z6039/6020 (9:1) Primer recommended by Dow Corning Corp.

Legend:

1. Unaffected
2. Slight dulling of surface
3. Noticeable dulling of surface
4. Light corrosion visible
5. Medium corrosion visible (10% of surface)
6. Heavy corrosion visible (over 20% of surface)
7. Discoloration of polymer
8. Delamination at interface

Table 3

CORROSION MONITORING - EVA

Test Specimens			Salt Spray Corrosion Conditions					
Notebook No.	Materials	Primer	24 Hrs	120 Hrs	300 Hrs	450 Hrs	700 Hrs	1600 Hrs
A8919-3	Aluminum in EVA, tab exposed	None	1	1	4,8	4,8	4,8	5,8
A8919-4	Galvanized steel in EVA	None	1	1	1	1	3	5,8
A8919-4	Galvanized, EVA, tab exposed	None	5	5	6,8	6,8	6,8	6,8
A8919-6	Mild steel in EVA	None	1	1	1	2	5,8	5,8
A8919-7	Mild steel, EVA, tab exposed	None	5	6	6,8	6,8	6,8	6,8
A8919-8	Galvanized steel, EVA	A8921-1	1	1	1	1	1	1
A8919-9	Mild Steel, EVA	A8921-1	1	1	1	1	1	1
	Mild Steel - Control	Uncoated	4	6	6	6	6	6
	Copper Control	Uncoated	4	6	6	6	6	6
	Aluminum Control	Uncoated	1	3	6	6	6	6
	Galvanized Control	Uncoated	4	6	6	6	6	6
	Unprotected Cell-Control	Uncoated	1	4	5	6	6	6
A8919-1	Aluminum in EVA	None	1	1	1	1	1	1
A8922-1	Copper in EVA	None	1	1	1	1	1	1
A8919-2	Aluminum in EVA	A8921-1	1	1	1	1	1	1
A8922-3	Copper in EVA	A8921-1	1	1	1	1	1	1
A8923-1	Solar Cell in EVA	None	1	1	1	1	1	1
A8923-2	Solar Cell in EVA	A8921-1	1	1	1	1	1	1
A8923-3	Solar Cell in EVA	GZ SS4179	1	1	1	1	1	1
A8920-1+2	Galvanic Cell, Copper-Zinc	None	1	1	1,9	1,9	3,9	3,9
A8921-2	Galvanic Cell, Copper-Zinc	A8921-1	1	1	1,9	1,9	3,9	3,9
A8921-3	Galvanic Cell, Cu-Zn,Wh.EVA	None	1	1	1,9	1,9	3,9	3,9
A8921-4	Galvanic Cell, Cu-Zn,Wh.EVA	A8921-1	1	1	1,9	1,9	3,9	3,9
A8922-4	Copper in EVA, tab exposed	None	1	1	5,8	5,8	5,8	5,8

1. Unaffected
2. Slight dulling of surface.
3. Noticeable dulling of surface.
4. Light corrosion visible.
5. Medium corrosion visible (10% of surface).

6. Heavy corrosion visible (over 20% surface).
7. Discoloration of polymer.
8. Delamination at interface.
9. No measurable current.

Table 4

CORROSION PROTECTION COMPARISON

Completely Encapsulated Metals
1600-Hour Exposure, ASTM-B117

Metal	EVA	EPDM	PU	PVC
(Unprimed)	1	1	1	4
Aluminum	1	1	1	4
Galvanized Steel	5	1	6	1
Mild Steel	5	4	6	6
Copper	1	4	6	2
(Primed) (a)				
Aluminum	1	1	2	1
Galvanized Steel	1	6	3	1
Mild Steel	1	2	6	5
Copper	1	2	2	2

Code:

- | | |
|----------------------------------|----------------------------|
| 1. Unaffected | 4. Light corrosion visible |
| 2. Slight dulling of surface | 5. Medium corrosion |
| 3. Noticeable dulling of surface | 6. Heavy corrosion |

(a) All specimens primed with mixture of Dow Corning primers;
Z-6030/Z-6029 (9:1)

SERIES I. EXPOSURES

Table 5

RS/4 FLUORESCENT SUNLAMP EXPOSURES

Notebook No.	Material	Formula	Cover	Exposure (Hours)	Color	Texture	OT	Modulus 100% 200% 300%	Elongation (%)	Tensile Strength (psi)
A8311A	PP6	6523	38B	11,500	None	Broken	--	--	--	--
A8311B	PP	6523	42A				B.			
A8311C	PP	6523	42B				B.			
A8901C	EVA	A8326	None	8,600	None	Okay	90.6	--	560	1870
A8001F	EVA	A8322A	NS-3315-42A	8,600	None	Okay	91.5	--	500	1930
A8901A	EVA	Elvax 150	None	4,000	Clear	Soft, Tacky	--	--	--	--
A8901B	EVA	Cured/Lupersol A8322A	None	4,000	Light Yellow	Soft, Tacky	--	--	--	--
A8901D	EVA - White	A8320B	None				B.			
A8901E	EVA	A8322A	Korad 201R	4,000	Slight Haze	Cover Brittle	--	--	--	--
A8901G	EVA	A8322A	SL Glass 4179 Prim.	4,000	Clear	Delamination	--	--	--	--
A8901H	EVA	A8322A	Glass 1 Korad	4,000	Clear	Bond Failure	--	--	--	--
A8901I	EVA	A8322A	B48N A6693-4	4,000	Clear	Coating Fractured	--	--	--	--
A8901J	Dorlux	--	None	4,000	Dark Brown	Same	--	--	--	--

A. Still shows sharp UV cutoff; OT% 200-350 nm

B. Still under exposure

SERIES II. EXPOSURES

Table 6

RS/4 FLUORESCENT SUNLAMP EXPOSURES

Specimens removed at the 60-day interval - degraded

Notebook No.	Material	Formula	Cover	Exposure (Hours)	Color	Texture	%T	Modulus 100% 200% 300%	Elongation (%)	Tensile Strength (psi)
A8926-1	EVA	Elvax 150	None	60 Day 1440	Light yellow	Soft/ Tacky	--	--	--	--
A8926-2	EVA	Lupersol A8915A	None	1440	Light yellow	Soft/ Tacky	--	--	--	--
A8926-9	EVA	Vulcup R A7717	None	1440	Yellow-Brown	Soft/ Tacky	--	--	--	--
A8926-10	EVA	A6996 Vynathane 903	None	1440	Yellow-Brown	Soft/ Tacky	--	--	--	--
A8926-11	EPDM/ EVA	Nordel 1320 A6992	None	1440	Dark Brown	V. soft/ Tacky	--	--	--	--
A8926-12	EPDM	Nordel 1320 w/ Silica	None	1440	Dark Brown	V. soft/ Tacky	--	--	--	--
60 Day Properties										
A8926-3	EVA	A8914-2	None	1440	Okay	Okay	--	315 384 443	688%	2,000
A8926-13	Korad	201-R	None	1440	Okay	Brittle	--	Broke 1.02 x 105	Broke	Broke
A8926-14	Tedlar	100-BG- 30 UT	None	1440	Okay	Okay		1.205 x 105	66.5%	16,790
A8926-15	Tedlar	400-XRB- 160-SE	None	1440	Okay	Okay		0.57 x 105	145%	12,085
A8926-16	EVA	A8326	None	1440	Okay	Okay		347 429 510	567%	1,216
A8926-17	EVA- White	A8320-B	None	1440	Okay	Okay		361 425 510	640%	1,875

SERIES II. EXPOSURES - (Continued)

RS/4 FLUORESCENT SUNLAMP EXPOSURES

Notebook No.	Material	Formula	Cover	Exposure (Hours)	Color	Texture	%T	Modulus 100% 200% 300%	Elongation (%)	Tensile Strength (psi)
60 Day Properties (a)										
A8926-4	EVA	A8914-2	Korad 201R	1440	Okay	Okay	90.5	--	--	--
A8926-5	EVA	A8914-2	Tedlar 100 BG-30 UT	1440	--	Okay	90.6	--	--	--
A8926-6	EVA	A8914-2	Glass 4179	1440	--	Delaminated	91.5	--	--	--
A8926-8	PVC	Monsanto	None	1440	Dark Yellow	Okay	74.6	--	--	--

(a) Evaluated for optical transmission only.

SERIES II. EXPOSURES

RS/4 FLUORESCENT SUNLAMP EXPOSURES

A8926 120 Day Properties

Notebook No.	Material	Formula	Cover	Exposure (Hours)	Color	Texture	%T	Modulus 100% 200% 300%	Elongation (%)	Tensile Strength (psi)
A8926-3	EVA	A8914-2	None	2,880	Okay	Okay		326 402 453	665%	1,724
A8926-13	Korad	201-R	None	2,880	Okay	Brittle/ Destroyed	--	Broke	Broke	Broke
A8926-14	Tedlar	100 BG- 30 UT	None	2,880	Okay	Okay		1.46 x 105	70%	16,819
A8926-15	Tedlar	400-XRB- 160-SE	None	2,880	Okay	Okay		0.6 x 105	133%	10,810
A8926-16	EVA	A8326	None	2,880	Okay	Okay	-	344 420 506	590%	1,233
A8926-17	EVA- White	A8320-B	None	2,880	Okay	Okay		361 425 510	650%	1,828

All 240 day A8926 spec. destroyed thermal override

SERIES III. EXPOSURES

Table 7

RS/4 FLUORESCENT SUNLAMP EXPOSURES

Al0561 - Specimens 60 Day Rejects

Notebook No.	Material	Formula	Cover	Exposure (Hours)	Color	Texture	%T	Modulus 100% 200% 300%	Elongation (%)	Tensile Strength (psi)
1, 2 Al0562-K	PU	Q621/ 626	None	1,440	Yellow/ Brown	Flowed	--	--	--	--
3, 4 Al0562-K	PU	Q621/ 626	None	1,440	Yellow/ Brown	Flowed	--	--	--	--
120 Day Exposure Specimens										
Al0562-A	EVA/ White	A9930B	None	2,880	Okay	Okay	--	258 379 psi 486	675	3,177
Al0562-B	EVA/ White	A9930	100 BG 30 UT Tedlar	2,880	Okay	Okay	--	282 432 546	625	2,088
Al0562-C	EVA/ White	A9930	201R Korad	2,880	Okay	Okay	--	256 382 psi 468	620	2,562
Al0562-D	EVA	A9918	None	2,880	Okay	Okay	--	233 349 psi 435	635	2,067
Al0562-E	EVA	A9918	100 BG 30 UT Tedlar	2,880	Okay	Okay	--	244 366 458	1,000	1,761
Al0562-F	EVA	A9918	201R Korad	2,880	Okay	Okay	--	248 358 445	637	2,345
Al0562-G	EPDM	A8945A	None	2,880	Okay	Okay	--	79 125 --	270	143
Al0562-H	EPDM	A8945A	100 BG 30 UT Tedlar	2,880	Okay	Okay	--	91 125 137	820	390
Al0562-I	EPDM	A8945A	201R Korad	2,880	Okay	Okay	--	103 132 143	317	697

SERIES III. EXPOSURES - (Continued)

RS/4 FLUORESCENT SUNLAMP EXPOSURES

120 Day Exposure Specimens

Notebook No.	Material	Formula	Cover	Exposure (Hours)	Color	Texture	%T	Modulus 100% 200% 300%	Elongation (%)	Tensile Strength (psi)
A10562-J	EPDM	A8945A	Glass	2,880	Okay	Okay		100 139 161	372	187
A10562-L	PU	Q621/ 626	201R Korad	2,880	Okay	Okay		210 494 --	252	788
A10562-M	PU	Q621/ 626	Tedlar 100 BG 30 UT	2,880	Okay	Okay		171 376 739	350	1,041
A10562-N	PU	Q621/ 626	Glass	2,880	Okay	Okay		114 246 463	377	922
A10562-O	EVA/ White	A9930	Glass	2,880	Okay	Okay	--	256 389 483	647	2,647
A10562-P	EVA	A9918	Glass	2,880	Okay	Okay		277 388 477	612	3,083

SERIES III. EXPOSURES

RS/4 FLUORESCENT SUNLAMP EXPOSURES

Al0561 -- 240 Day Exposure

Notebook No.	Material	Formula	Cover	Exposure (Hours)	Color	Texture	%T	Modulus 100% 200% 300%	Elongation (%)	Tensile Strength (psi)
Al0561-A	EVA/W	A9930	None	5,760	Okay	Okay	--	300 400 469	725	3,000
Al0561-B	EVA/W	A9930	Tedlar 100 BG 30 UT					237 385 455	835	2,450
Al0561-C	EVA/W	A9930	Korad 201R					310 400 490	810	2,800
Al0561-D	EVA	A9918	None	5,760	Okay	Okay		380 520 450	535	1,500
Al0561-E	EVA	A9918	Tedlar 100 BG 30 UT	5,760	Okay	Okay		290 380 445	630	1,350
Al0561-F	EVA	A9918	Korad 201R	5,760	Okay	Okay		310 420 475	675	2,050
Al0561-G	EPDM	A8945A	None					80 97 --	275	102
Al0561-H	EPDM	A8945A	Tedlar 100 BG 30 UT	5,760	Okay	Okay		105 -- --	178	130
Al0561-I	EPDM	A8945A	Korad 201R	5,760	Okay	Okay		130 140 160	457	205
Al0561-J	EPDM	A8945A	Glass	5,760	Okay	Okay		135 165	265	175

SERIES III. EXPOSURES - (Continued)

RS/4 FLUORESCENT SUNLAMP EXPOSURES

A10561 - 240 Day Exposure

Notebook No.	Material	Formula	Cover	Exposure (Hours)	Color	Texture	%T	Modulus 100% 200% 300%	Elongation (%)	Tensile Strength (psi)
A10561-L	PU	Q621/ 626	Korad 201R	5,760	Okay	Okay		230 450	263	71
A10562-M	PU	Q621/ 626	Tedlar 100 BG 30 UT	5,760	Yellow	Flowed		--	--	--
A10562-N	PU	Q621/ 626	Glass	5,760	Okay	Okay		120 210 380	440	960
A10562-O	EVA/W	A9930	Glass	5,760	Okay	Okay		330 420 490	722	2,550
A10562-P	EVA	A9918	Glass	5,760	Okay	Okay		425 500 610	700	2,850
A10562-Q	GE Silicone	534-044	None	5,760	Okay	Okay				
A10562-R	GE Silicone	534-044	201R Korad	5,760	Okay	Okay				